DIURNAL TESTING OF OFF-ROAD EQUIPMENT RETROFITTED WITH CARBON CANISTER EVAPORATIVE EMISSION CONTROL SYSTEMS (March 2003)

Stationary Source Testing Branch
Monitoring and Laboratory Division

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Introduction

To determine the effectiveness of a carbon canister system to control diurnal evaporative emissions from off-road equipment with engines ≥255 cc, the California Air Resources Board (ARB) recently modified and tested a 5000 watt generator and a 16.5 Hp commercial riding mower. Each was retrofitted with a prototype carbon canister evaporative emission control system.

Staff worked with an automotive canister manufacturer to procure and configure two off-the-shelf carbon canisters and developed a purge and control system for use in the test program. Tests were performed to measure the hot soak and diurnal emissions of the equipment in uncontrolled and controlled configurations. In addition, canister performance was evaluated on the modified equipment over an extended soak period. Each piece of equipment was subjected to repeated annual average temperature profiles while modified. Diurnal emissions were then measured at 7, 14, and 21-day intervals using California's episodic temperature profile. This report summarizes staff's evaluation.

Test Protocol for Baseline and Controlled Testing

Three baseline and three controlled tests were performed on each piece of equipment. Prior to performing baseline tests, staff preconditioned the equipment's fuel system by soaking them with summer pump fuel for a minimum of ninety days.

After the preconditioning period, staff performed three baseline hot soak and diurnal tests on each piece of equipment using the following test sequence:

Baseline Test Sequence

- Drain and fill tank with 2.5 gallons of fresh summer pump fuel
- Operate equipment under normal load for 15 minutes
- Perform a one hour hot soak test at 95º F
- Purge and cool SHED to 65º F
- Soak equipment at 65º F for two hours
- Perform a 24-hour diurnal test using California's episodic variable temperature profile (65º F - 105º F - 65º F).

Following the baseline testing, equipment was retrofitted with a 6-gallon metal fuel tank passively (unrestricted) vented to a 670-cc carbon canister. Low permeation fuel and vapor lines were also used to minimize evaporative and permeation emissions. The carburetor port of each canister was directly connected to an intake tap made in each of the engine's intake manifolds. A direct connection was used to facilitate 'back-purge' during changes in ambient temperature. The controlled testing was performed using the following test sequence:

Controlled Test Sequence

- Drain and fill tank with 2.5 gallons of fresh summer pump fuel
- Operate equipment under load for 15 minutes
- Perform a one hour hot soak test at 95º F
- Purge and cool SHED to 65º F
- Soak equipment at 65º F for two hours
- Perform a 24-hour diurnal test using California's episodic variable temperature profile (65º F - 105º F - 65º F).
- Cap the tank port of the canister and connect a purge line to the carburetor
- Purge the canister with a vacuum pump set at 10 LPM for 30 minutes

Canister Retrofit Results

Figures 1 and 2 compare the uncontrolled and controlled hot soak and diurnal emissions for each of the tests of the generator and commercial riding mower.

Figure 1

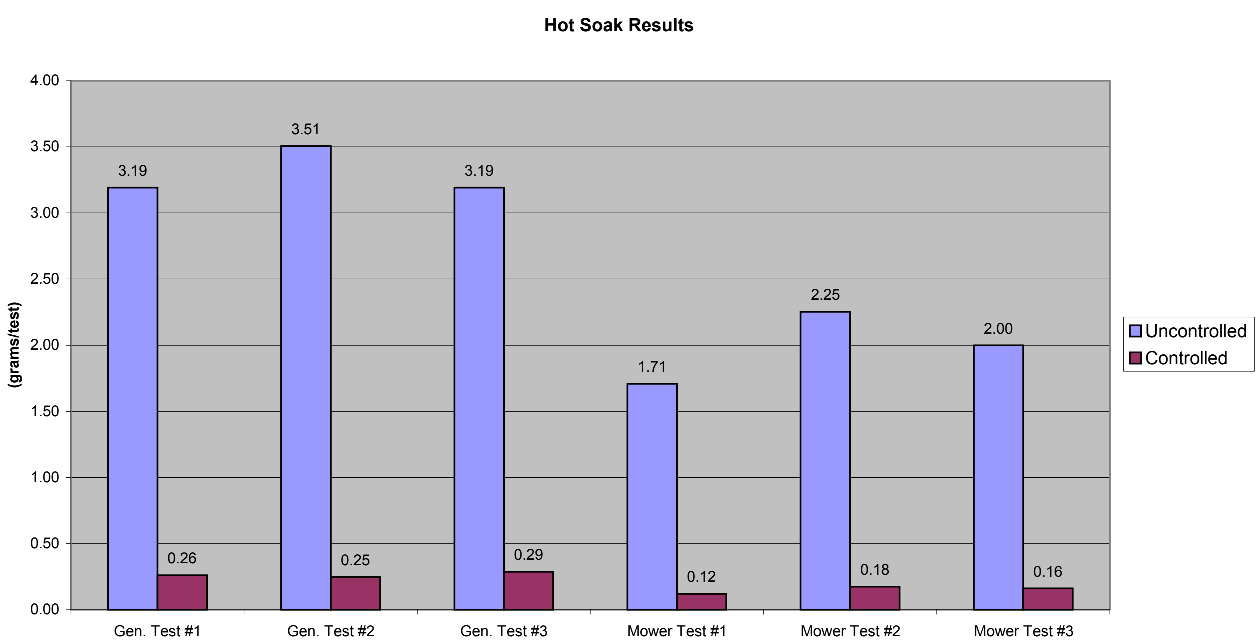
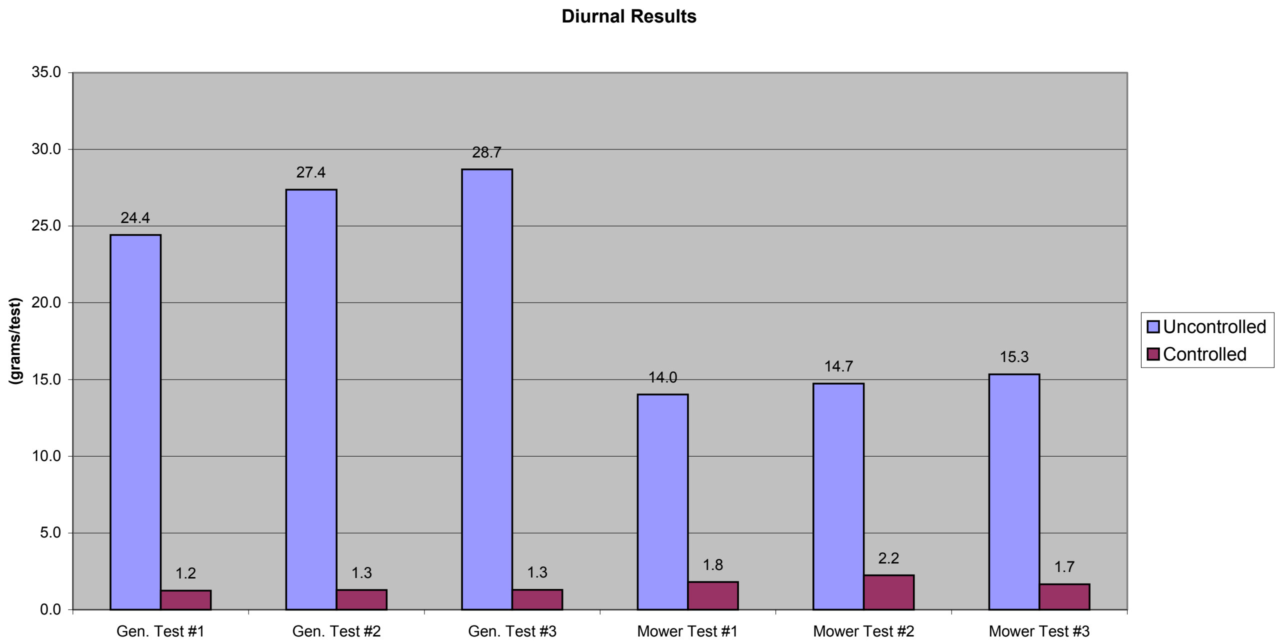


Figure 2



Test Protocol for Canister Testing over an Extended Soak Period

In addition to the previous tests, staff evaluated canister performance on the modified generator and commercial riding mower over an extended soak period. To accomplish this, the modified equipment was soaked in a SHED for 21 days using an annual average temperature profile (see Attachment 2). To determine the effectiveness of the canister systems, diurnal emissions were measured at 7, 14, and 21-day intervals using California's episodic temperature profile (see Attachment 1).

Staff performed the equipment soak and the 7, 14, and 21-day diurnal emissions testing using the following test sequence:

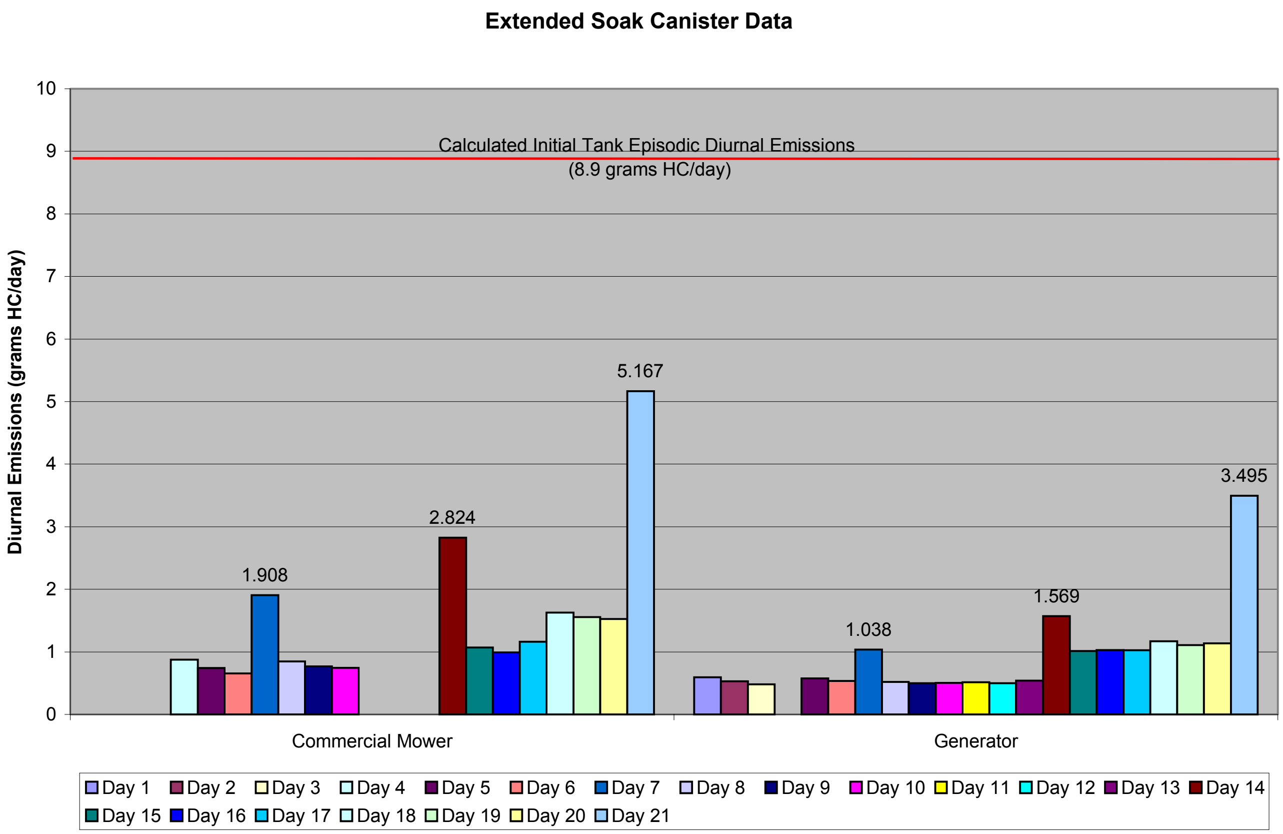
- Drain tank and fill with 2.5 gallons of fresh summer pump fuel (6.9 RVP)
- Soak equipment in SHED for six days (Day 1 –6) subjecting it to repeated annual average temperature profiles (See Attachment 2).
- Purge the SHED
- Perform a 24-hour diurnal test using California's episodic variable temperature profile (65º F - 105º F - 65º F).
- Purge the SHED
- Soak equipment in SHED for six days (Day 8 –13) subjecting it to repeated annual average temperature profiles

- Purge the SHED
- Perform a 24-hour diurnal test using California's episodic variable temperature profile (65º F - 105º F - 65º F).
- Soak equipment in SHED for six days (Day 15 –20) subjecting it to repeated annual average temperature profiles
- Purge the SHED
- Perform a 24-hour diurnal test using California's episodic variable temperature profile (65º F - 105º F - 65º F).

Extended Soak Results

Figure 3 summarizes the diurnal emissions results of the extended soak testing.

Figure 3



Equipment were subjected to an annual average temperature profile (see Attachment 2) on Days 1-6, 8-13, and 15-20. It should be noted that several data points corresponding to annual average temperature profile days are not shown in Figure 3. Unfortunately, some of the equipment 'soaking' was done using the ARB's Running Loss (RL) SHED which does not have the ability to quantify diurnal emissions. The RL SHED was used to maintain the appropriate temperature profile only. The initial tank evaporative emissions (8.9 grams

HC/day) were calculated from the “Reddy” equation using the following conditions:

Reddy Equation

(grams HC/gallon vapor space)= $A * Exp(B * RVP) * (Exp(C * T2) - Exp(C * T1))$

Where:

A = 0.00817
B = 0.2357
C = 0.0409
T2 = Final Fuel Temperature (105º F)
T1 = Initial Fuel Temperature (55º F)
RVP = Fuel Reid Vapor Pressure (6.9) in pounds per square inch
Vapor Space = 3.5 gallons

Conclusion

As shown in Figure 3, the use of a carbon canister can significantly reduce diurnal evaporative emissions. When both the commercial riding mower and the generator were repeatedly subjected to California’s annual average temperature profile, diurnal evaporative emissions remained well below 2.0 grams per day throughout the 21-day soak period. Additionally, when both equipment were tested on the 7th day using the episodic temperature profile, emissions remained below the current 2.0 gram per day proposed diurnal evaporative emissions standard. The data indicates that carbon canisters could be used to achieve significant long-term evaporative emission reductions.

Attachment 1

1 Day / 24 Hour / 1440 Minute Episodic Variable Temperature Profile

HOUR	MINUTE	TIME REMAINING (MINUTES)	TEMPERATURE (°F)
0	0	1440	65.0
1	60	1380	66.6
2	120	1320	72.6
3	180	1260	80.3
4	240	1200	86.1
5	300	1140	90.6
6	360	1080	94.6
7	420	1020	98.1
8	480	960	101.2
9	540	900	103.4
10	600	840	104.9
11	660	780	105.0
12	720	720	104.2
13	780	660	101.1
14	840	600	95.3
15	900	540	88.8
16	960	480	84.4
17	1020	420	80.8
18	1080	360	77.8
19	1140	300	75.3
20	1200	240	72.0
21	1260	180	70.0
22	1320	120	68.2
23	1380	60	66.5
24	1440	0	65.0

Attachment 2

1 Day / 24 Hour / 1440 Minute Annual Average Variable Temperature Profile

HOUR	MINUTE	TIME REMAINING (MINUTES)	TEMPERATURE (°F)
0	0	1440	55.3
1	60	1380	54.6
2	120	1320	54
3	180	1260	53.6
4	240	1200	53.2
5	300	1140	53.2
6	360	1080	54.3
7	420	1020	56.8
8	480	960	60.4
9	540	900	63.8
10	600	840	66.5
11	660	780	68.6
12	720	720	70
13	780	660	70.8
14	840	600	71.1
15	900	540	70.6
16	960	480	68.9
17	1020	420	66.2
18	1080	360	63.2
19	1140	300	60.7
20	1200	240	59
21	1260	180	57.8
22	1320	120	56.8
23	1380	60	56
24	1440	0	55.3